BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Saturn V Launch Vehicle Engine-Out and Ground Wind Structural Capability - Case 330

DATE: April 11, 1967

FROM: H. E. Stephens

ABSTRACT

Emergency Detection System (EDS) and structures review efforts at MSFC have confirmed that a Saturn V launch vehicle structural strength problem exists for loss of an engine at max Qα. For some combinations of wind and engine loss, the "controlled" case, it was found that vehicle breakup would be almost instantaneous. Other combinations, the "uncontrolled" case, were found to lead to divergent vehicle motion and subsequent loss, but with warning time.

This memorandum discusses the launch vehicle engine-out loads and responses, critical vehicle stations, and the program initiated by MSFC to obtain a structural "fix." Structural strengthening to solve the divergent (uncontrolled) case is not feasible, however some warning time is available for abort. In the "controlled" case of engine loss at max Qα it was found that almost instantaneous breakup could be averted by providing structural strengthening of several joints. An estimated 110 pound increase in the vehicle weight and a 103 pound loss of payload capability would result in a 1.0 factor of safety for the peak loads. This change would gain crew safety warning time. If a larger factor of safety, say 1.4, were required, a 2,887 pound payload loss would result. It is concluded that use of the 1.0 factor of safety for this loading case appears reasonable. The zero margin of safety requires the following:

a. 95 percentile winds.

b. worst case engine loss at or near max Qα.

c. structural capability no more than design values -- tests stopped before failure in most cases.

[redacted]

[redacted]

39 (ACCESSION NUMBER)	2A (THRU)
39 (PAGES)	(CODE)
NR-84648 (NASA CR OR TMX OR AD NUMBER)	31 (CATEGORY)

FACILITY FORM 602

(NASA-CR-154367) SATURN 5 LAUNCH VEHICLE ENGINE-OUT AND GROUND WIND STRUCTURAL CAPABILITY (Bellcomm, Inc.) 39 p

N79-72164

Unclas
00/15 12457

BELLCOMM, INC.

TABLE OF CONTENTS

TABLES

Table of Contents (Cont'd)

FIGURES

BELLCOMM, INC.

SUBJECT: Saturn V Launch Vehicle Engine-Out and Ground Wind Structural Capability - Case 330

DATE: April 11, 1967

FROM: H. E. Stephens

MEMORANDUM FOR FILE

1. INTRODUCTION

The Boeing Company presented the results of a preliminary Emergency Detection System (EDS) engine-out analysis at the Sixth Flight Limits Subpanel Meeting on November 9, 1966.[1] The results of that study indicated that for certain one engine-out failures vehicle breakup would occur almost instantaneously. Control system response, attitude rates and warning times were also included in the study. Further refinements of the November 1966 results were made and a second briefing given on January 11, 1967,[1] (herein referred to as EDS Study).

MSFC, R-P&VE, gave a presentation to Dr. A. Rudolph on February 27, 1967, covering the latest analyses of one engine-out and ground wind structural requirements and recommendations for structural strengthening (herein referred to as Structures Report). The author attended that presentation.

Continuing efforts are underway at MSFC to investigate the structural loading and capability, EDS limits and warning times, and control system characteristics for the one engine-out case at maximum $Q\alpha$. Although both the EDS Study and Structures Report indicated a serious structural condition for one engine-out at maximum $Q\alpha$, the detailed findings differed, i.e., the most critical joint. This is attributed to a refinement in assessed structural capability. This memorandum discusses the launch vehicle loading, structural capability, and recommendations for structural strengthening.

2. CRITICAL FLIGHT TIME

The maximum aerodynamic bending, which must be counterbalanced by engine gimballing to maintain programmed attitude rates, is introduced into the vehicle at maximum $Q\alpha$. In some wind

---

[1]Trip Report - EDS Effectiveness: Status of Saturn V Launch Vehicle Analyses, Case 320, dated January 12, 1967, by T. F. Loeffler and M. M. Purdy.

conditions, this will result in a net tension load in portions of the launch vehicle. Loss of an engine, the particular engine depending on the wind direction, can increase this tension beyond the structural capability. Once through maximum $Q\alpha$, although the compressive axial acceleration load continually increases until S-IC center-engine cutoff, the bending moments for a nominal flight decrease. As loss of an engine superimposes additional bending moments, maximum $Q\alpha$ (approximately T + 70 seconds) is structurally the most critical time for loss of an engine.

3. ENGINE-OUT LOADS

Figures 1 through 3 are included to show in simplified form the impact on structural loading of loss of an engine at maximum $Q\alpha$. Figure 1 represents the loading condition just prior to loss of an engine. As illustrated, the aerodynamic lift force tends to rotate the vehicle clockwise about the CG, M_α. To counteract this moment, the engines are gimballed to provide a counterclockwise moment M_β. (NOTE: M_α and M_β will not be equal as some transients in attitude rates (angular acceleration) will be permitted when passing through maximum $Q\alpha$.) This vehicle loading is analogous to a beam in which compression is introduced at the top and tension at the bottom. The bending load is superimposed on the axial compressive load caused by drag and longitudinal acceleration. In some nominal flight conditions, the bending stress will exceed the axial compressive stress and a net tension will be present. This situation is illustrated in Figure 1.

Figures 2 and 3 show the added (unbalanced) moment caused by loss of an engine, but before engine gimbal correction. The wind direction establishes the relative velocity vector and hence the plane in which the angle of attack, α, lies. This "α" plane determines which specific engines are the most critical. As shown later, worse case wind directions were chosen so that α would be in either the 2-4 or 1-3 engine planes. Hereinafter, loss of the engine on the same side of the longitudinal axis as α is referred to as the "controlled" case and the opposite engine as the "uncontrolled" case.

The "controlled" engine loss case is shown in Figure 2. Loss of the engine reduces the counterclockwise engine gimbal moment, M_β, to approximately three-fourths of its value prior to engine loss. The unsymmetrical longitudinal engine thrust now introduces a counterclockwise disturbing moment, M_{EO}. This moment M_{EO} is significantly greater than the reduction in M_β, resulting in an unbalanced counterclockwise moment approximately equal to $M_{EO}-\Delta M_\beta$. For structural loading, the acceleration forces generated are equivalent to applying a static moment that will increase the tension loads on the bottom of the vehicle forward of the CG. The tension capability is almost instantaneously exceeded at certain vehicle stations. To obtain control of the vehicle, in simplified form, the engine gimbal angles must be changed to create a clockwise moment equal to $M_{EO} - M_{\alpha}$. This means shifting β to the opposite side of the longitudinal axis.

The "uncontrolled" engine loss case is shown in Figure 3. In this case, the engine-out disturbing moment, M_{EO}, is in the same direction as M_{α}. Initially, the tension load is relieved and only compression is present at the critical joints. The engines must be gimballed an amount to counterbalance $M_{EO} + M_{\alpha}$ with three engines. This case has been shown to lead to divergent attitude rates with an increase in α and tension loads. The response for this case is favorable in that some warning time for an abort is present.

4. EDS STUDY

Some of the aspects of the EDS Study that relate to the Structures Report are covered below.

a. Wind Conditions

Two directional wind loading cases were used. These were:

(1) 41 knots (21 meters/second), 27°. With reference to paragraph 3, #1 engine is the controlled case and #3 engine the uncontrolled case.

(2) 135 knots (69 meters/second), 297°. With reference to paragraph 3, #2 engine is the controlled case and #4 engine the uncontrolled case.

b. α vs β curves

Initially, structural criticality was evaluated by use of α vs β limit curves. A typical α vs β limit curve for station 2747 (S-IVB Aft separation joint) is shown by Figure 4. The α vs β limit curves will vary by station. As a refinement, the dynamic response, including bending and axial loads, was computed by the Boeing Company Saturn V Flight Dynamics Digital Program. As would be expected, there was not complete agreement with the α vs β limits. As a result, the refined loads from the Flight Dynamics Program rather than the α vs β curves were used as the failure criteria.

However, it is noted that the α vs β curves remain of value. A tabulation of the equations used for this Flight Dynamics Program are available from the author. It is noted that 19 panels along the length of the vehicle for summing the aerodynamic forces and 51 mass concentrations points are used. This program also permits the use of a flexible body analysis, as well as that of a rigid body, and has provision for injection of simulated malfunctions. A profile of vehicle motions, rates and structural loads is provided. Typical attitude rate and structural tension load output curves are shown in Figures 5 and 6.

c. Critical Joint

The first EDS Study work determined vehicle station 1848, S-II common bulkhead bolting ring, to be the most critical joint; whereas the Structures Report did not include this as a critical joint. This is attributed to a significant revision upward of station 1848 capability from that used in the EDS Study.

d. Continuing Work

The prime purpose of the EDS Study effort is not to solve the structural problems. Rather, it is to investigate vehicle dynamics behavior, attitude rates, stability problems, warning times, and control systems. Nevertheless, the EDS Study work is dependent on assessed structural strengths and, likewise, the Structures work dependent on the output from the EDS Study. In discussions with MSFC personnel, the author found that in fact these two efforts were being coordinated and worked together. The EDS Study is a continuing effort.

5. STRUCTURES REPORT

The Structures Division, R-P&VE, MSFC, has an effort underway to review the Saturn V structural capability to withstand an engine-out at maximum $Q\alpha$. This effort also extends to the ability to withstand a 65 knot ground wind while on the launch pad. The scope of this work includes a redefinition of vehicle loading, reassessment of vehicle structural capability, identification of critical points and possible fixes, and initiation of a program leading to a "fix."

a. Wind Conditions

As noted in paragraph 4, 41 and 135 knot directional winds were considered in the EDS Study. In assessing the structural capability, the wind loadings are further related to desired factors of safety. The Structures Report considers a maximum wind velocity of 146 knots, compared to the 135 knots used in the EDS Study.

Loading information was generated and the structural capability examined for four cases of engine-out at maximum Qα, which are:

146 knots (75 meters/sec); factor of safety 1.4
146 knots; factor of safety 1.0
88 knots (45 meters/sec); factor of safety 1.4
88 knots; factor of safety 1.0

The 1.4 factor of safety means that the ultimate strength at which the vehicle will break up is 1.4 times the loads expected; in this case, the loads after loss of an engine at maximum Qα. A 1.0 factor of safety means that the structure will just take the expected load without breakup, any greater load causing failure. Also, yielding of the structure will occur under the expected load.

The 146 and 88 knot cases represent the same actual wind, but with trajectory bias considered in the 88 knot case. With trajectory bias in the pitch plane, attitudes are programmed for the mean wind corresponding to the planned month of launch. That is, the attitude pitch is aligned into the wind for a crabbing type motion. By taking advantage of trajectory bias for a mean wind, MSFC found that the 146 knot wind could be handled by an equivalent 88 knot wind loading rather than the full 146 knots.

b. Loading Information

Axial load, bending moment, and flexural response information was generated for different vehicle stations to establish new design load profiles.

A typical response curve is shown in Figure 7 for station 2832 (S-IVB LH_2 tank to aft skirt). The controlled vehicle response curve (left side) is for the engine-out case illustrated in Figure 2. As can be seen, in Figure 7, there is a rapid buildup in tension load to a peak with a subsequent gradual decrease. The general shape of the curve is determined by the vehicle and control system responses. The oscillations in the curve are due to excitation of vehicle flexure modes. If it is possible to get the vehicle past the first peak, it can withstand the subsequent loading. The uncontrolled vehicle response curve (right side Figure 7), is for the engine-out case illustrated in Figure 3. In this case, there is not an instantaneous buildup of tension loads, but a divergence in vehicle attitude rates with a continuing load increase. Again the oscillations in the curve represent excitation of vehicle flexure modes.

As seen in Figure 7, there is little similarity between the controlled and uncontrolled cases. In the controlled case, there is a rapid buildup of tension followed by a gradual decrease, whereas in the uncontrolled case there is a divergence and continued load increase. However, in the uncontrolled case there is warning time available before the structural loads approach the ultimate strength. Providing adequate strength to withstand the ultimate uncontrolled case load appears to be out of the question. That problem is being investigated by the EDS Study from the aspect of warning times and possible control system changes and a discussion of that effort is not part of this memorandum. The structures review effort is being addressed to the controlled case and to providing sufficient strength to withstand the first (maximum) peak in the vehicle loading. That peak is presently predicted to occur within a fraction of a second and without sufficient warning time for crew abort.

The vehicle moment load profiles generated as a basis for a review of the structural capability are shown in Figure 8. The present design moment profile is included, as well as the new ones for the engine-out cases with and without wind bias. The relative severity of these moment curves is illustrated by their maximum bending moments, which are:

Case	Maximum Bending Moment in-lbs
Design criteria	270×10^6
88 knot wind, one engine-out	415×10^6
146 knot wind, one engine-out	510×10^6

Figure 9 shows a breakdown of the moment curve of Figure 8 for a 88 knot wind into its components; these being engine-out static and dynamic moments, bending moments due to α and β, and a dynamic moment due to wind (gusts). The engine-out dynamic moment shown in Figure 9 is due to excitation of the vehicle flexure modes (oscillations shown in Figure 7). A significant portion of the bending moment in the top portions of the vehicle, where many of the structural weaknesses were found, is attributable to this dynamic moment.

Responses from the first four bending modes and the wind gust loading were superimposed as if in phase in the MSFC Structures Study. Although this direct superimposition could be conservative, in the actual case this should provide a slight margin of safety, particularly where a 1.0 factor of safety is used.

The axial loads are combined with these bending moments (similar to that shown in Figure 1) to obtain the maximum tension and compression loads at each station of the vehicle.

c. Strength Capability

A reassessment of the tension and compression capabilities of the various joints and sections of the vehicle has been made. In so doing, design loads, analysis, and structural test information were considered. Tables I through IV, taken from the Boeing Company SA-501 Structural Integrity Report of February 6, 1967, give a summary of the structural test program including the percentage of the limit load* to which the components have been tested. In some cases, the components were tested to the design 1.4 factor of safety without failure occurring. As those tests were to demonstrate that the design factor of safety had been achieved, they were stopped at that point and not taken to destruction. Conceivably, there may be some margin of safety** at the critical joints. The exact amount of any margin of safety is unknown and should be determined. If it is found that any of the joints have a margin of safety beyond the design factor of safety, the structural "fix" for an engine-out capability would be easier.

Figures 11 and 12, also taken from the Boeing February 6, 1967, SA-501 Structural Integrity Report, summarize the assessed compression and tension capabilities respectively for SA-501 in pounds per inch of circumference. The assessed compression capability is based entirely on test information, whereas the tension capability is based primarily on design and analysis.

The structural capabilities shown are for SA-501. In determining the profile for SA-504 and subs, allowance is made for those sections and joints whose configuration and design factor of safety have changed. Less test information is available on the SA-504 and subsequent configuration than for SA-501.

---

*Limit Load - Limit load is the maximum load calculated to be experienced by the structure under the specified conditions of operation. In this instance, based on the Design Moment curve of Figure 8.

**Margin of Safety - As used here, margin of safety means the

$$\frac{\text{Actual Ultimate Strength}}{\text{Limit Load}} - 1.4.$$

TABLE I

S-IC MAJOR STRUCTURAL TEST PROGRAM

MAJOR TESTS	LOAD CONDITIONS	RESULTS	DATE OF TEST
D-31 S-IC-S OXIDIZER TANK ASSEMBLY (SA-501 THROUGH SA-503)	CUTOFF EMPTY	140% (NO FAILURE)	7-12-66
	CUTOFF ULLAGE	140% (NO FAILURE)	7-28-66
	LAUNCH REBOUND	140% (NO FAILURE)	7-29-66
D-32 S-IC-S FUEL TANK ASSEMBLY	STATIC FIRING TEST	140% (NO FAILURE)	6-21-65
	GROUND WIND	140% (NO FAILURE)	10-28-65
	LAUNCH REBOUND	140% (NO FAILURE)	12- 2-65
	FLIGHT CUTOFF	140% (NO FAILURE)	3- 1-66
	MAX $q\alpha$	140% (NO FAILURE)	2-14-66
	HEATSHIELD	158% (FAILURE)	3-17-66
D-36 SR_2 INTERTANK	MAX $q\alpha$	161% (FAILURE)	2-25-66

TABLE I (CONT'D)

S-IC COMPONENT STRUCTURAL TEST PROGRAM

TEST	LOAD CONDITIONS	RESULTS	DATE OF TEST
D-20 S-IC-C FUEL TANK	HYDROSTATIC	105% (PROOF)	10-22-64
	INERTIAL LOADS	137% (NO FAILURE)	2-18-65
JOINT TENSION TEST (STATION 1541)	GROUND WINDS	378% LIMIT LOAD (FAILURE)	6-10-66
D-33 FIN & ENGINE FAIRING	LAUNCH	140% (NO FAILURE)	4-12-66
	FIN	140% (NO FAILURE)	6-21-66
	FAIRING (R.T.)	100% (NO FAILURE)	4-15-66
	FAIRING (ELEVATED)	140% (NO FAILURE)	6- 6-66

TABLE II

S-II STRUCTURAL TEST PROGRAM

TESTS	LOAD CONDITIONS	RESULTS	DATE OF TEST
		MAJOR TESTS	
S-II	PRELAUNCH	140% LIMIT (NO FAILURE)	JULY 1965
	MAX $q\alpha$	130% LIMIT (FAILURE IN FWD SKIRT	SEPT 1965
	END OF S-IC BOOST	138% LIMIT (FAILURE IN INTERSTAGE)	SEPT 1965
	ENGINE THRUST LOADING	140% LIMIT (NO FAILURE)	APRIL 1965
	AFT LOX BULKHEAD	126% LIMIT (FAILURE OF SUMP ATTACH BOLTS)	MARCH 1966
S-II/S-IVB INTERFACE TEST	MAX $q\alpha$ (INCLUDING PRESS)	140% LIMIT (NO FAILURE)	AUG 1966
	S-IC CUTOFF (INCLUDING TEMP & PRESS)	140% LIMIT (FAILURE IN INTERSTAGE) AT 520°F	SEPT 1966
		COMPONENT TESTS	
COMMON BULKHEAD	AMBIENT TEMP TEST	105% LIMIT PRESS (NO FAILURE)	JULY 1965
	CRYOGENIC CYCLIC TEST	100% LIMIT PRESS (NO FAILURE)	SEPT 1965
	CRYOGENIC TEMP ULTIMATE PRESS AND MAX $q\alpha$ LOADING	130% LIMIT LOAD (NO FAILURE)	NOV 1965

TABLE III

S IV B STRUCTURAL TEST PROGRAM

TESTS	LOAD CONDITIONS	RESULTS	DATE OF TEST
		MAJOR TESTS	
FWD SKIRT	MAX $q\alpha$	101% LIMIT AXIAL LOAD 250% LIMIT BENDING MOMENT (FAILURE)	JULY 1966
LH_2 TANK CYLINDERICAL SECTION	GROUND WINDS	140% LIMIT AXIAL LOAD 240% LIMIT BENDING MOMENT (FAILURE)	SEPT 1964
AFT SKIRT	MAX $q\alpha$	100% LIMIT AXIAL LOAD 225% LIMIT BENDING MOMENT (FAILURE)	SEPT 1966
LH_2 HYDRO-STATIC NO. 2	LH_2 TANK (ULTIMATE)	142% LIMIT PRESS (FAILURE)	SEPT 1966
	LOX TANK (ULTIMATE)	140% LIMIT PRESS (FAILURE)	SEPT 1966
		COMPONENT TESTS	
JOINT TENSION TEST (STATION 2746)	GROUND WINDS	224% LIMIT LOAD	MAY 1964
JOINT TENSION TEST (STATION 2519)	MAX $q\alpha$	TEST IN PROGRESS	

TABLE IV

IU STRUCTURAL TEST PROGRAM

TEST	LOAD CONDITION	RESULTS	DATE OF TEST
S-IU-200/500S-2	MAX $q\alpha$	140% LIMIT AXIAL LOAD 140% LIMIT BENDING MOMENT (FAILURE)	FEB 1966
S-IU-500 RETEST	MAX $q\alpha$	140% LIMIT AXIAL LOAD 140% LIMIT BENDING MOMENT (NO FAILURE)	SEPT 1966

d. Critical Joints (General)

The factors of safety for the different cases considered were determined by dividing the structural strength capabilities by the generated loads. For the joints where this figure was less than the desired factor of safety (negative margin of safety) a preliminary estimate was made of the increase in vehicle weight required to bring the factor of safety up to that desired.

Table V is the R-P&VE tabulation of the results of such a review for a 146 knot (75 meters/second) wind and 1.4 factor of safety. The vehicle was found to be critical in compression throughout and in tension in the S-II and up. It was estimated that for a factor of safety of 1.4, vehicle weight would increase by 19,280 pounds with a payload loss of 8,754 pounds. This represents the extreme case; that is, increasing the structural capability to 1.4 times the expected engine-out loads without consideration of trajectory bias.

Table VI gives the results for the 146 knots (75 meters/second) and 1.0 factor of safety case. The 1.0 factor of safety means that the ultimate structural capacity is the same as the maximum expected loads. The vehicle was found to be critical in tension at eight locations and in compression at one location. It was estimated that for a factor of safety of 1.0, the vehicle weight would increase by 380 pounds with a payload loss of 296 pounds.

Table VII gives the results for the 88 knots (45 meters/second) and 1.4 factor of safety case. As was found for 146 knots and a 1.4 factor of safety, the vehicle was generally critical in both compression and tension. It was estimated that for a factor of safety of 1.4, the weight would increase by 4,356 pounds with a payload loss of 2,887 pounds.

Table VIII gives the results for 88 knots (45 meters/second) and a 1.0 factor of safety. In this case, the vehicle is capable of withstanding the compression loads, but is critical in tension at six locations. For a factor of safety of 1.0, the estimated weight increase and payload loss are 110 and 103 pounds respectively.

TABLE V

SATURN V ONE ENGINE OUT STUDY

t = 70 SEC, 75 M/S WIND   F.S. = 1.4

STATION	STRUCTURAL COMPONENT	CRITICAL IN COMPRESSION	CRITICAL IN TENSION	WEIGHT INCREASE	PAYLOAD LOSS	COMMENTS
3258						
3222	INSTRUMENT UNIT	X	X	300	300	REDESIGN
3100	FORWARD SKIRT	X	X	850	850	REDESIGN
	LH_2 TANK	X	X	1140	1140	REDESIGN
2832						
2746	AFT SKIRT	X	X	650	650	REDESIGN
2519	INTERSTAGE	X	X	1850	1850	REDESIGN
2387	FORWARD SKIRT	X	X	890	341	REDESIGN
	LH_2 TANK	X	X	9300	3170	REDESIGN
1847						
1760	AFT SKIRT	X	X	100	30	RESIZE LOWER INTERFACE FOR TENS.
1564	INTERSTAGE	X	X	450	133	RESIZE STR., FRAMES; REDESIGN INTERFACE & SEPARATION JOINTS
1401	FORWARD SKIRT	X		450	35	REDESIGN SKIN
	LOX TANK	X		800	62	REDESIGN SKIN & STRINGERS
912						
602	INTERTANK					
365	FUEL TANK	X		1200	93	REDESIGN SKIN & STRINGERS
100	THRUST STRUCTURE	X		1300	100	REDESIGN THRUST POST & THRUST STRUCTURE SKINS
			TOTAL	19280	8754	

TABLE VI

SATURN V ONE ENGINE OUT STUDY

t = 70 SEC, 75 M/S WIND F.S. = 1.0

STATION	STRUCTURAL COMPONENT	CRITICAL IN COMPRESSION	CRITICAL IN TENSION	WEIGHT INCREASE	PAYLOAD LOSS	COMMENTS
3258						
3222	INSTRUMENT UNIT	X	X	100	100	REDESIGN
3100	FORWARD SKIRT		X	80	80	INCREASE FLANGE THICKNESS AT STA. 3222.6 & 3100
	LH_2 TANK					
2832						
2746	AFT SKIRT		X	80	80	INCREASE FLANGE t AND BOLT DIA. AT STA. 2832. INCREASE TENS. STRAP THICKNESS AT STA. 2746
2519	INTERSTAGE					
2387	FORWARD SKIRT		X	40	12	FWD INTERFACE, INCREASE S-IVB FLANGE THICKNESS & INCREASE BOLT DIAMETER
	LH_2 TANK					
1847						
1760	AFT SKIRT					
1564	INTERSTAGE		X	80	24	INCREASE TENSION STRAP AREA AT STATIONS 1564 & 1760
1401	FORWARD SKIRT					
	LOX TANK					
912						
602	INTERTANK					
365	FUEL TANK					
100	THRUST STRUCTURE					
			TOTAL	380	296	

TABLE VII

SATURN V ONE ENGINE OUT STUDY

t = 70 SEC, 45 M/S WIND F.S. = 1.4

STATION	STRUCTURAL COMPONENT	CRITICAL IN COMPRESSION	CRITICAL IN TENSION	WEIGHT INCREASE	PAYLOAD LOSS	COMMENTS
3258						
3222	INSTRUMENT UNIT	X	X	200	200	REDESIGN
3100	FORWARD SKIRT	X	X	550	550	REDESIGN
	LH_2	X	X	650	650	REDESIGN THE WAFFLE CYL. SECTION
2832						
2746	AFT SKIRT	X	X	300	300	REDESIGN
2519	INTERSTAGE	X	X	800	235	REDESIGN
2387	FORWARD SKIRT	X	X	106	31	REDESIGN
	LH_2 TANK	X	X	2400	706	REDESIGN CYLINDRICAL SECTION
1847						
1760	AFT SKIRT		X	50	15	RESIZE LOWER INTERFACE FLANGES & BOLTS
1564	INTERSTAGE		X	100	30	RESIZE SEPARATION PLANE HDWE & INTERFACE JOINT HARDWARE
	LOX TANK					
912						
602	INTERTANK					
365	FUEL TANK	X		900	70	REDESIGN TANK WALL & STRINGERS
100	THRUST STRUCTURE	X		1300	100	REDESIGN THRUST POST & THRUST STRUCTURE SKINS
			TOTAL	7356	2887	

TABLE VIII

SATURN V ONE ENGINE OUT STUDY

t = 70 SEC, 45 M/S WIND F.S. 1.0						
STATION	STRUCTURAL COMPONENT	CRITICAL IN COMPRESSION	CRITICAL IN TENSION	WEIGHT INCREASE	PAYLOAD LOSS	COMMENTS
3258						
3222	INSTRUMENT UNIT		X	20	20	INCREASE UPPER RING SIZE
3100	FORWARD SKIRT		X	50	50	RESIZE UPPER INTERFACE RING
	LH_2					
2832						
2746	AFT SKIRT		X	30	30	UPPER JOINT: RESIZE BOLTS & FRAME FLANGE
2519	INTERSTAGE					SEPARATION PLANE: INCREASE t OF TENSION SEGMENT
2387	FORWARD SKIRT					
	LH_2 TANK					
1847						
1760	AFT SKIRT					
1564	INTERSTAGE		X	10	3	RESIZE THE TENSION STRAP DESIGN AT UPPER & LOWER SEPARATION PLANES
1401	FORWARD SKIRT					
	LOX TANK					
912						
602	INTERTANK					
365	FUEL TANK					
100	THRUST STRUCTURE					
			TOTAL	110	103	

The weight increase and payload loss for these four cases are summarized as follows:

Knots (Wind)	Meters/sec	Desired Factor of Safety	Weight Increase (pounds)	Payload Loss (pounds)
146	(75)	1.4	19,280	8,754
146	(75)	1.0	380	296
88	(45)	1.4	7,356	2,887
88	(45)	1.0	110	103

e. Specific Critical Joints (88 knot wind, F.S. 1.0)

The following locations were found to be critical for this controlled engine-out case.

(1) IU, Upper Ring (Station 3258) (SLA Interface)

The amount of bond area between the inboard ring flange of the IU upper ring and the inboard skin was found to be critical. An increase in the length of the inboard ring flange and bond area is required.

(2) IU/S-IVB Interface (Station 3222)

The IU and the S-IVB forward skirt are joined by internal bolting ring flanges. When tension is applied to the joint, the rings act as cantilever beams between the bolting circle and the outer skin. The dimensions are such that under a tension load, the flange on the S-IVB forward skirt becomes critical in bending. One way that this could be rectified would be to rivet tension straps across the outside of the joint. Such a procedure has the distinct disadvantage that the IU and S-IVB could not be readily demated. Other possible fixes, such as reinforcing bathtub fixtures on the S-IVB side, are to be investigated.

(3) S-IVB LH_2 Tank/Aft Skirt Joint (Station 2832)

The bolting ring flanges are critical in tension in the same manner as for the IU/S-IVB forward skirt. A possible fix would be to place washers, or rings, under the bolt heads and nuts to stiffen the flanges. Other methods are to be investigated.

(4) S-IVB/S-II Separation Plane (Station 2746)

Tension loads across the separation plane are carried by a tension band located on the outside of the linear shaped separation charge. In staging, this band is severed by the shaped charge. It was found the band does not now have enough cross section area to carry the engine-out tension load. A proposed fix is to increase the thickness of the tension band to provide the required cross section area. Whether the required band thickness is within the range that can be severed by the shaped charge is questionable at this time. This is to be investigated, along with whether a new qualification program will be required for the revised configuration.

(5) S-II Separation Planes (Stations 1760 and 1564)

The same type problem as for the S-IVB aft skirt/ interstage separation plane (station 2746) exists at the two S-II separation planes, except that tension straps rather than a band are used. It appears that the required cross section area can be obtained by increasing the width of the present tension straps. If so, this should not lead to shaped charge qualification problems.

(6) S-IVB/S-II Interface

Although not included in Table VIII, later information indicates that the bolt diameter at station 2519 will be increased.

f. MSFC Course of Action

MSFC is proceeding with the following plan to obtain a structural fix for the engine-out case:

(1) By use of panel tests, structurally test the following tension joints of the SA-504 configuration to ultimate strength (5 samples each location):

Station #	Location
3258	IU to SLA
3222	S-IVB to IU
3100	S-IVB LH_2 tank to S-IVB forward skirt
2832	S-IVB LH_2 tank to aft skirt
2747	S-IVB separation plane
1760	S-II forward separation plane
1564	S-II aft separation plane

(2) Use a factor of safety of 1.0 rather than 1.4 and an 88 knot (45 meters/second) wind rather than 146 knots (75 meters/second).

(3) Have contractors evaluate the joints based on these loads and recommend their fix and any required additional tests.

6. GROUND WIND

The vehicle (504 and subs) has been examined for its capability to withstand a 65 knot peak ground wind at the 60 foot level while standing on the launch pad. A desired 1.4 factor of safety was used and both the empty and fueled conditions with damper installed were considered.

a. Empty Vehicle

The bending moment profile for this case is shown in Figure 10. As shown, the compression capability of the forward portion of the S-II LH_2 tank is marginal. This can be alleviated by a change in the operational procedure to maintain a 5 psi pressure, vice 3.5, in the tank under this condition. The S-II dual separation planes were found to be critical in tension, as was the case for the engine-out condition. If the necessary strength is provided in these straps to withstand the 88 knot, 1.0 factor of safety, engine-out case, a 1.4 factor of safety for this ground wind will also be provided. Of the two separation planes, the aft one is the more critical. It presently has a 1.0 factor of safety for this loading condition, while the forward S-II separation plane has 1.35.

b. Fueled Vehicle

It was found that the vehicle has a 1.4 factor of safety without modification or change in operational procedure.

7. DISCUSSION/CONCLUSIONS

a. EDS Study

The EDS Study pointed up that structural problems exist for the engine-out case at maximum $Q\alpha$. A separate, but related, "structural fix" program has been initiated. This EDS effort is continuing with respect to EDS parameters and flight crew safety.

b. Structures Review Effort

(1) Engine-Out

The structural capability has undergone preliminary examination to determine the amount of strengthening required to withstand engine-out loads with factors of safety of 1.4 and 1.0. The "controlled" case with a 1.4 factor of safety represents strengthening the vehicle to the extent that loss of an engine would not jeopardize continuing on with at least an alternate mission. As noted, this would result in an estimated 8,754 and 2,887 pound payload loss for the 146 and 88 knot wind cases, respectively, as well as some redesign of the vehicle. The payload loss alone is serious. Impact of a vehicle redesign and consideration for the uncontrolled case (Figure 7) are also important factors. Strengthening would not provide a 1.4 factor of safety for the uncontrolled case, which, however, is predicted to provide warning time before breakup.

The 1.0 factor of safety means that the structure will be stressed right up to its ultimate capacity to withstand the engine-out loads. The amount of structural strengthening required is based on the structural load first peak in the controlled engine-out case (Figure 7). It does not provide capability to withstand the eventual buildup in structural loads for the uncontrolled engine case. This 1.0 factor of safety then does not provide complete assurance that the flight can continue. Rather, it is intended to provide warning time for crew safety in the controlled engine-out case.

Many factors must be considered in determining the acceptability of the 1.0 factor of safety in view of the tremendous payload losses of the 1.4 factor of safety. Some of these are:

(1) Probability that the 95 percentile wind will prevail for the flight.

(2) Probability of loss of an engine.

(3) Probability that the engine will be lost at max $Q\alpha$.

(4) If an engine is lost at max $Q\alpha$, the probability that it will be the worse case engine.

(5) Conservatism, or inherent margin of safety, in the predicted vehicle loading, response, and structural capability.

The "fix" to accommodate the 146 knot wind is accomplished entirely by structural strengthening. On the other hand, the 88 knot "fix" allows for trajectory bias. Payload loss is very similar, being 296 pounds for 146 knots and 103 pounds for 88 knots. In both cases, the tension band or straps at separation planes are critical in cross section area. Staging requires that these be severed by the linear shaped separation charges. Even in the 88 knot wind case, the new required thickness of the S-IVB aft skirt/interstage tension band is near the limit thought capable of severence by the present separation plane/charge design. A requalification program may be required. To increase this thickness to that required for the 146 knot wind would surely lead to a redesign. Also, no compression "fix" is required for 88 knots. Although the payload loss is similar for the two wind cases, the structural "fix" for 88 knots is simpler with less impact.

There is some slight conservatism in the determination of the loads used for the 1.0 factor of safety engine-out case. For example, the first four flexure modes were evaluated and these and the wind gust loading superimposed as if in phase. Loss of the worst case engine for the wind direction and at the most critical flight time, maximum $Q\alpha$, have been used. In establishing the joint strengths, capabilities larger than either the design load or the load to which the joints had been tested were not used. As shown in

Tables I through IV, in many cases the structural tests were only up to the design factor of safety for design verification, not to ultimate capacity. Some of the joints may have an actual ultimate load greater than the design limit. If so, this could conceivably reduce the structural "fix" required or might even provide a factor of safety greater than 1.0. As noted above, MSFC is proceeding with panel tests of the critical joints. The sample of five tests for each location should adequately define the joint capabilities and verify the proposed "fixes." MSFC has also started the stage contractors analyzing the joints in depth for determination of the best possible "fix."

(2) 65 Knot Ground Wind

This was discussed in paragraph 6. In summary, increased width of the S-II dual separation plane tension straps (which is also required for the 88 knot, 1.0 factor of safety, engine-out case) and an increase of the S-II empty LH_2 tank pressure from 3.5 to 5.0 psi will give a 1.4 factor of safety for the empty vehicle. As presently configured, the vehicle has a 1.4 factor of safety while standing on the pad in the fueled condition in the same wind.

c. Conclusions

Based on the above discussion, it is concluded that:

(1) Use of a 1.0 design factor of safety in determining the structural fix for the controlled engine-out case appears justified. Under the worst case loading, the structure will be worked up to its ultimate strength with significant yielding. This would preclude continuing on with even an alternate mission. It will, as intended, provide warning time for crew safety. Serious payload losses would result if the vehicle were strengthened to a 1.4 factor of safety for the controlled engine-out case. Even so, this would not necessarily preclude vehicle loss in the uncontrolled engine-out case.

(2) The program defined and initiated by MSFC will lead to a "fix" for the controlled engine-out case. Determination of ultimate strengths by the panel tests included in the program is necessary. A serious payload loss is not expected to result from the "fix."

J. J. O'Connor for

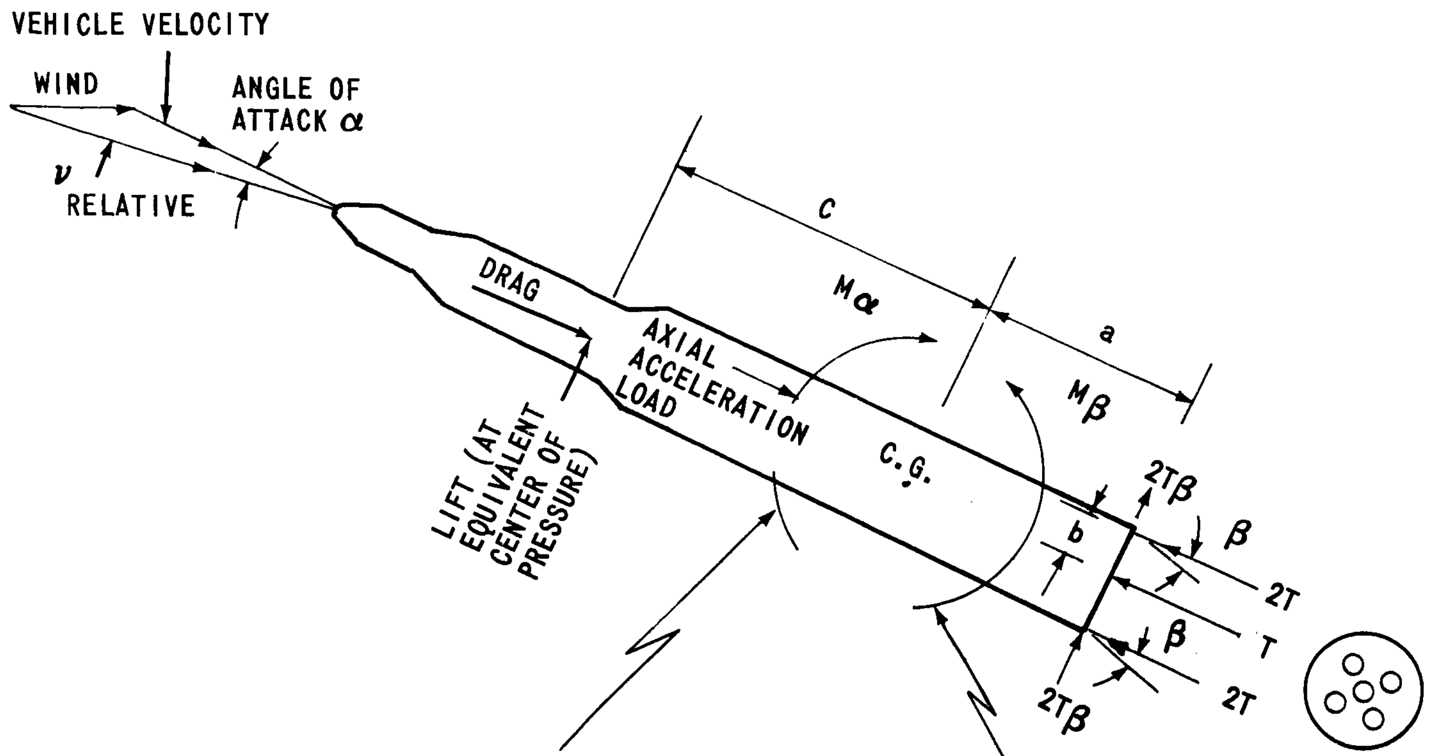
2031-HES-sjh H. E. Stephens

Copy to
Messrs. C. H. Bolender - NASA/MO-1
L. E. Day - NASA/MAT
G. F. Esenwein, Jr. - NASA/MAT
J. K. Holcomb - NASA/MAO
L. B. James - NASA/MA-A
T. A. Keegan - MASA/MA-2
S. C. Phillips - NASA/MA
M. L. Seccomb - NASA/MA
J. H. Turnock - NASA/MA-4
G. C. White, Jr. - NASA/MAR

L. Jenkins - MSC/PD4
P. D. Smith - MSC/ES12
D. C. Wade - MSC/ES2

L. Bell - MSFC/I-V-E
P. W. Frederick - MSFC/R-P&VE
G. A. Kroll - MSFC/R-P&VE
W. R. Lucas - MSFC/R-P&VE
L. Richard - MSFC/R-TO-DIR
A. Rudolph - MSFC/I-V-MGR
N. Showers - MSFC/R-P&VE
J. T. Stevens - MSFC/R-P&VE

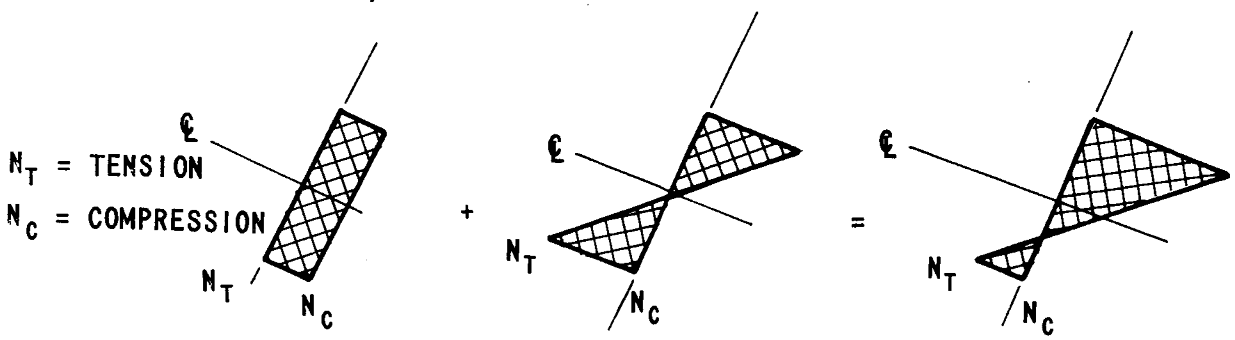
G. M. Anderson
C. Bidgood
D. R. Hagner
P. L. Havenstein
W. C. Hittinger
B.T. Howard
B. Kaskey
J. Z. Menard
I. D. Nehama
T. L. Powers
I. M. Ross
W. Strack
T. H. Thompson
J. M. Tschirgi
G. B. Troussoff
R. L. Wagner
Central Files
Department 1023
Department 2031
Library



AERO LIFT MOMENT, $M\alpha$, TENDS TO ROTATE CLOCKWISE ABOUT C.G.
$M\alpha$ = (LIFT) (C)

ENGINE GIMBAL MOMENT, $M\beta$, TENDS TO ROTATE COUNTERCLOCKWISE ABOUT C.G. TO BALANCE AERO MOMENT, $M\alpha$
$M\beta = 4(T\beta)$ (a)

$M\alpha$ & $M\beta$ SUPERIMPOSE TENSION LOADS ON BOTTOM AND COMPRESSION ON TOP AS FOLLOWS (CAN RESULT IN NET TENSION ON BOTTOM);



AXIAL LOADS　　BENDING　　NET LOADS

NOTE:

FOR CLARITY, GRAVITY & NOMINAL RATE CHANGE ACCELERATION LOADS NOT SHOWN

FIGURE I - SATURN V - SIMPLIFIED CONTROL MOMENTS JUST PRIOR TO ENGINE LOSS AT MAX. $Q\alpha$ ($T + 70^s$)

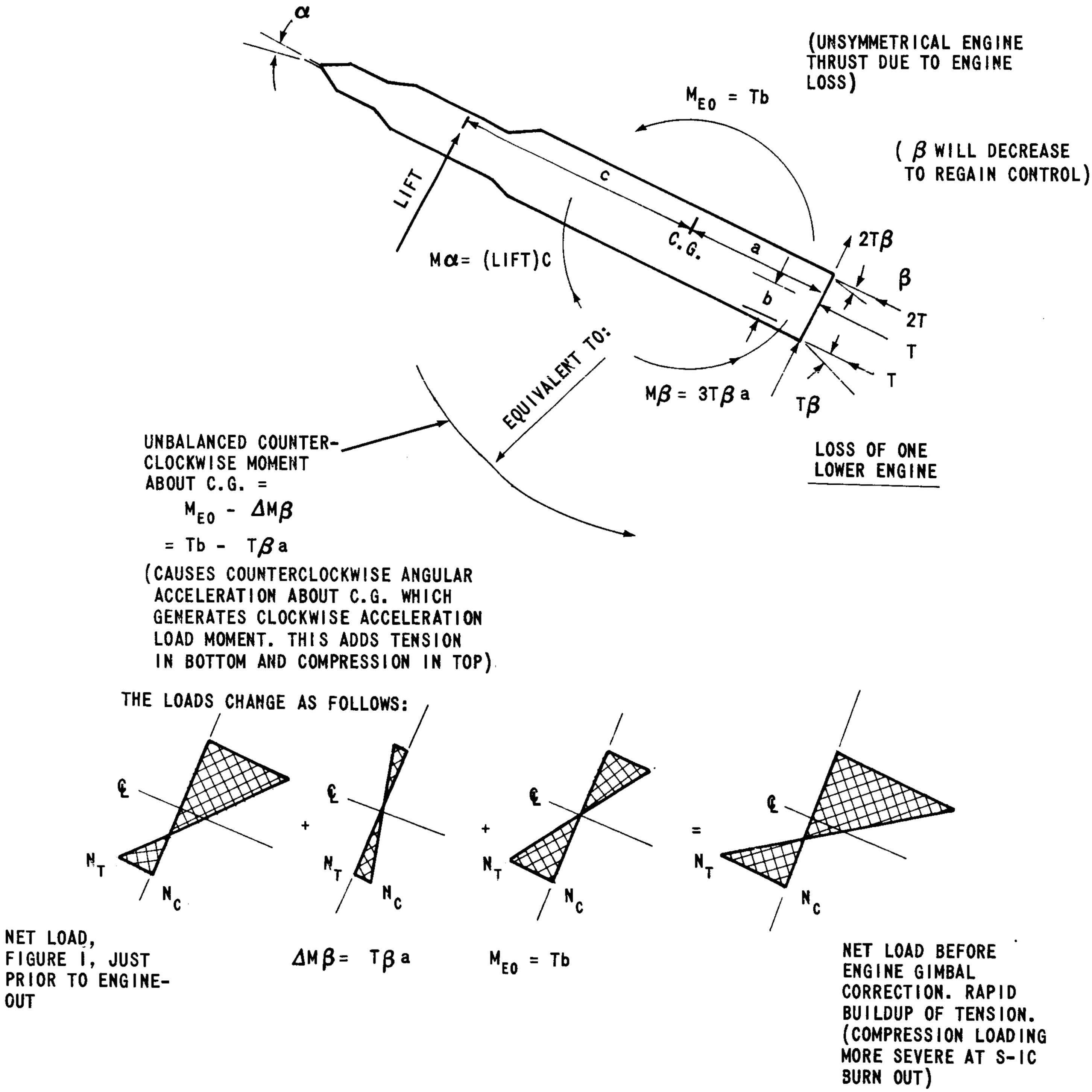
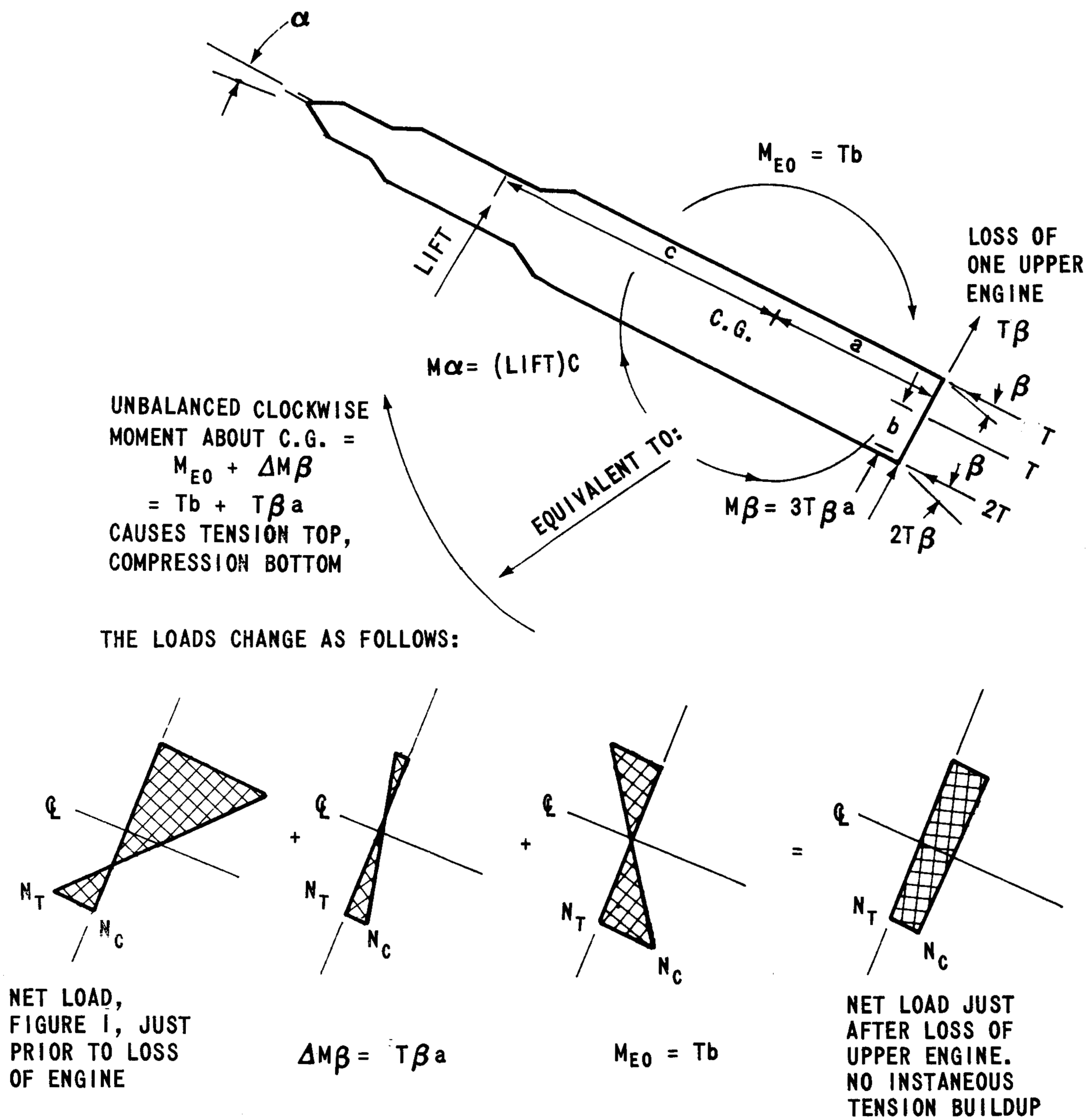


FIGURE 2 - SATURN V - DISTURBING MOMENTS JUST AFTER LOSS OF LOWER ENGINE AT MAX $Q\alpha$



NOTES:

1. RAPID STRUCTURAL OVERLOAD NOT PRESENT AS FOR LOSS OF LOWER ENGINE, FIGURE 2.

2. INITIAL UNBALANCED MOMENT IS $2T\beta a$ GREATER THAN FOR LOSS OF LOWER ENGINE. ALTHOUGH NOT CAUSING INSTANTANEOUS BREAKUP THIS CASE WAS FOUND TO LEAD TO INSTABILITY CAUSING EVENTUAL STRUCTURAL OVERLOAD, BUT WITH WARNING TIME.

FIGURE 3 - SATURN V - DISTURBING MOMENTS JUST AFTER LOSS OF UPPER ENGINE AT MAX Q α

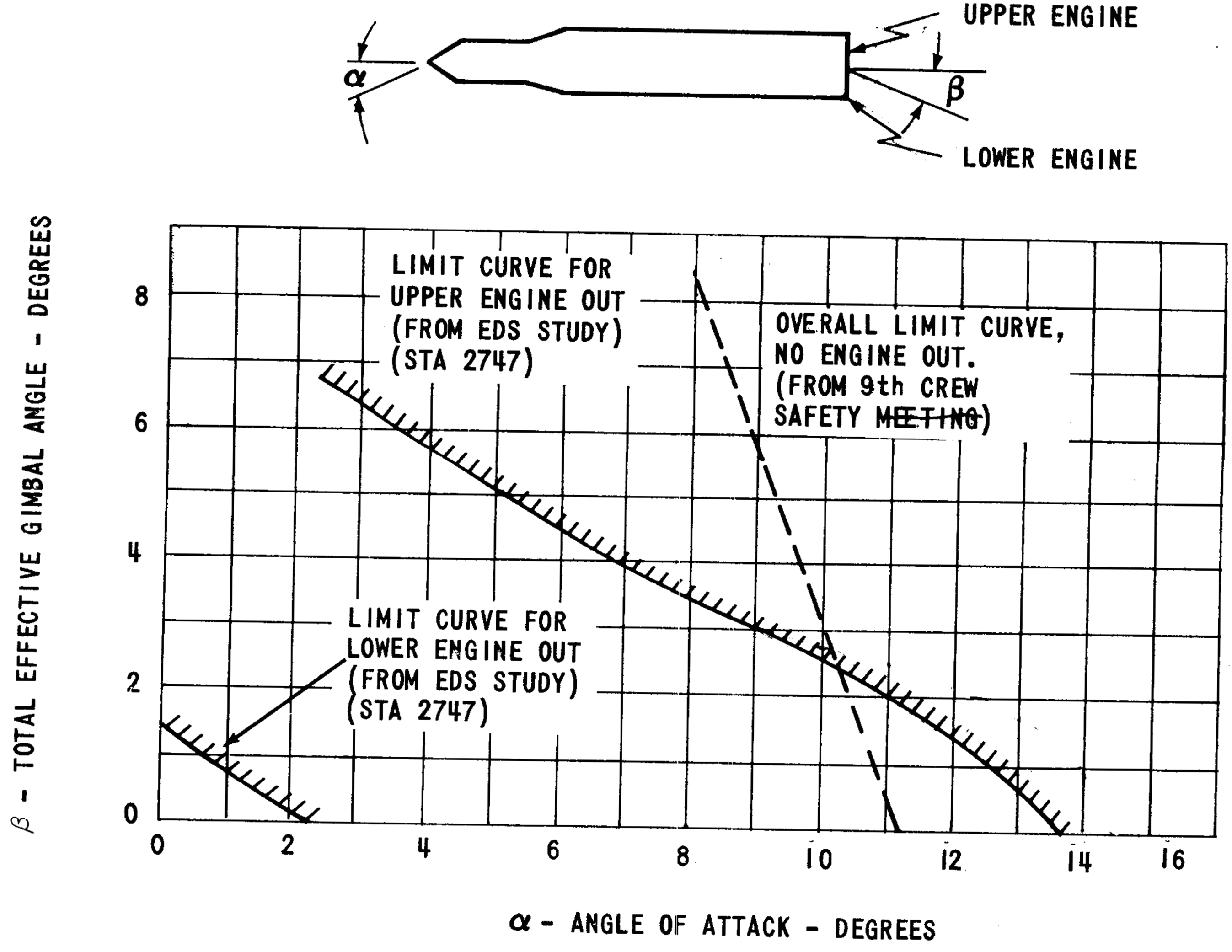


FIGURE 4 - SATURN V - α VS β STRUCTURAL LIMITS AT MAX. Q α FOR STATION 2747

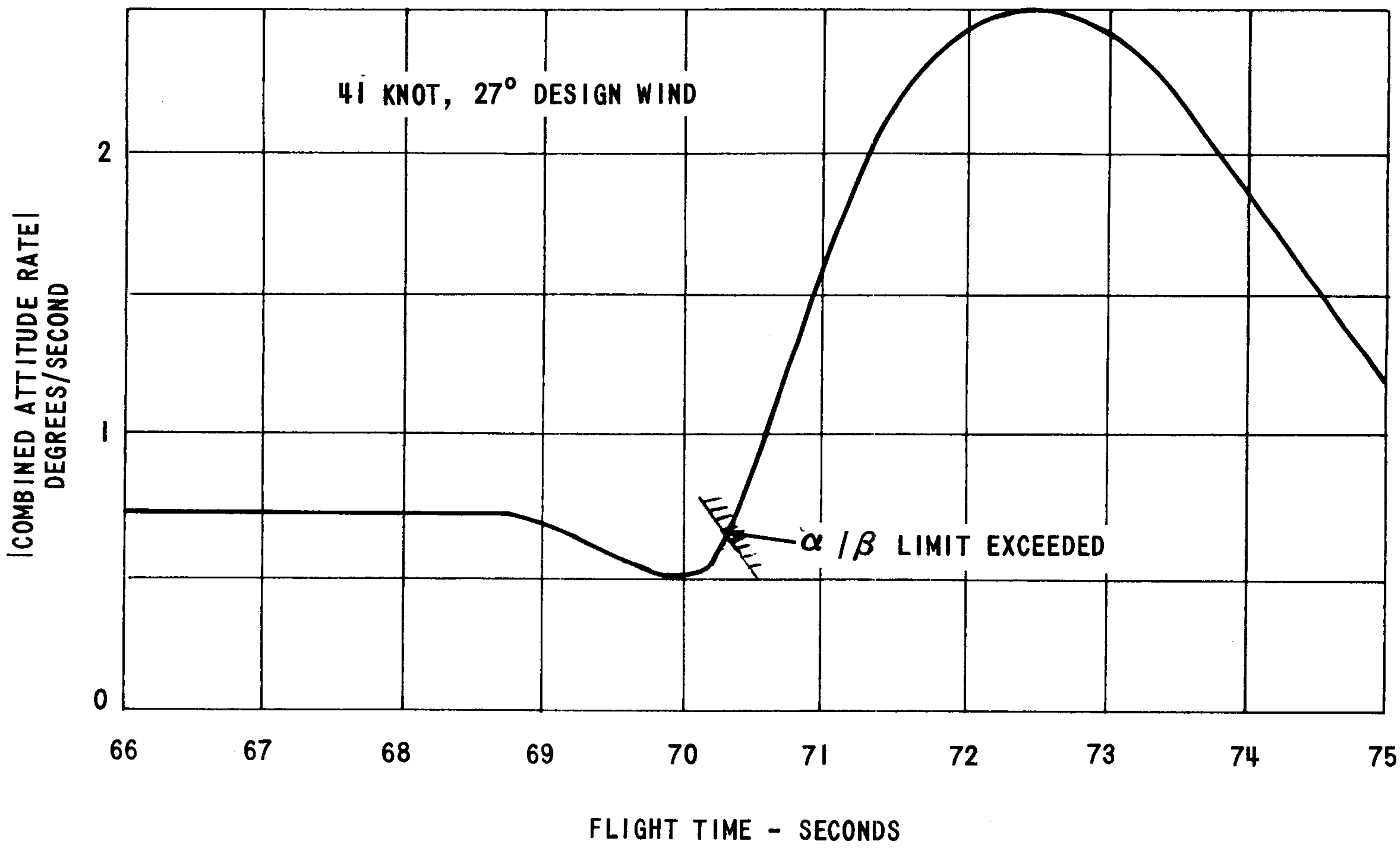


FIGURE 5 - SATURN V - TYPICAL ATTITUDE RATE CURVE FROM EDS STUDY, #1 (LOWER) ENGINE OUT AT T+70 SECONDS

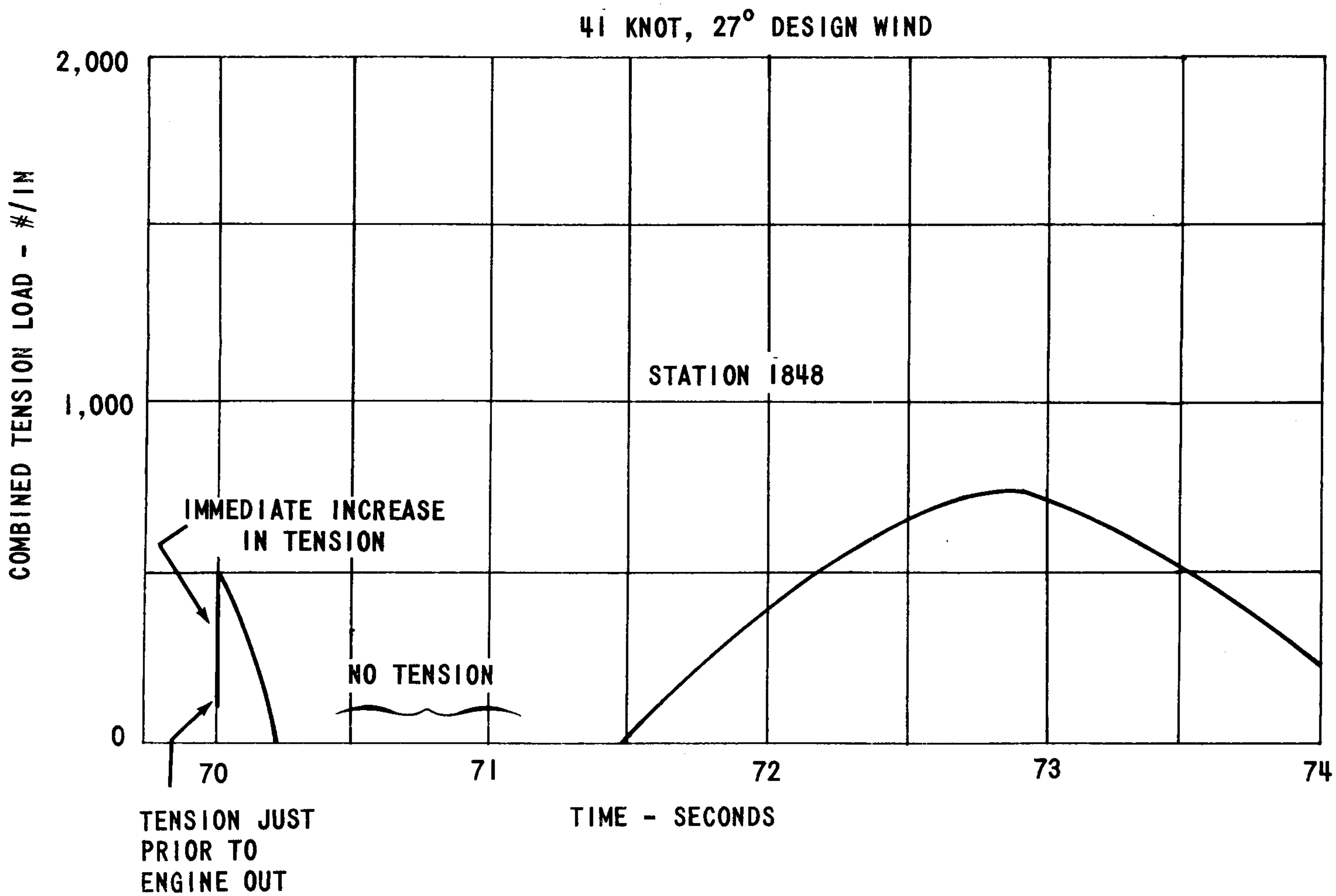


FIGURE 6 - SATURN V TYPICAL STRUCTURAL TENSION LOADING CURVE FROM EDS STUDY. #1 (LOWER) ENGINE OUT AT T+70 SECONDS. STATION 1848

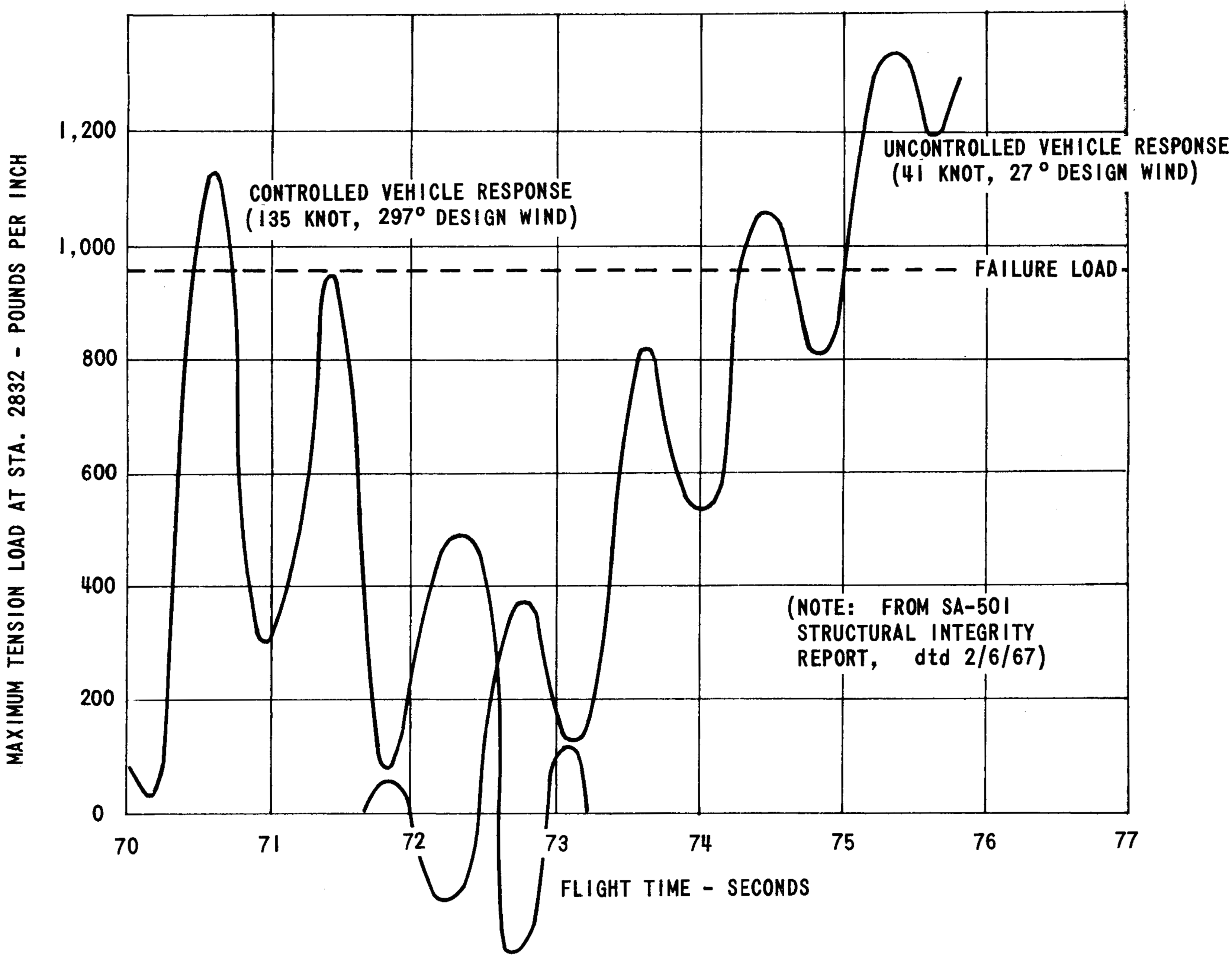


FIGURE 7 - SATURN V - COMPARISON OF LOAD VERSUS TIME. CONTROLLED VEHICLE VERSUS UNCONTROLLED VEHICLE ENGINE-OUT AT 70 SECONDS

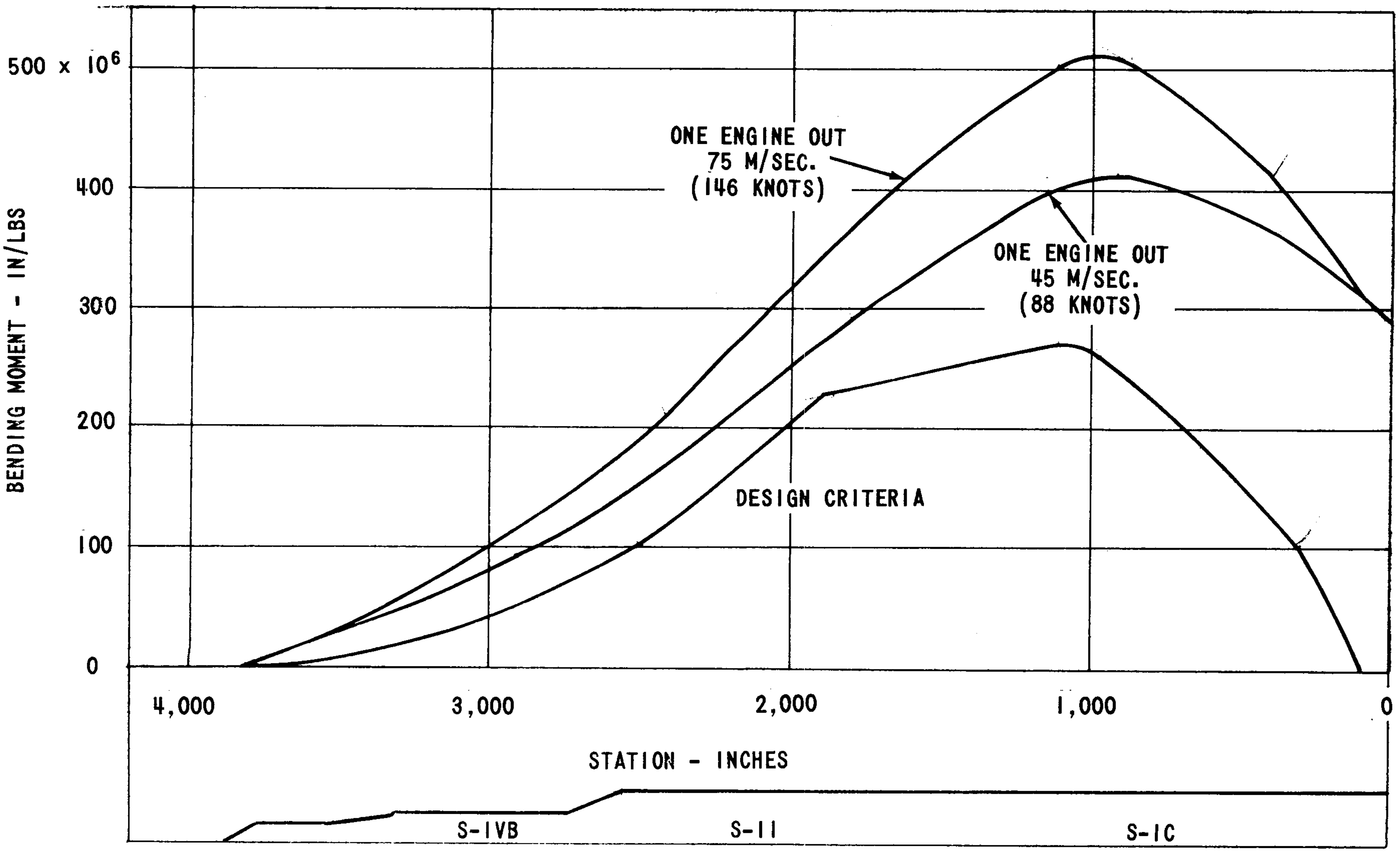


FIGURE 8 - SATURN V - BENDING MOMENT COMPARISON $t = 70$ SEC. MAX. $Q\alpha$

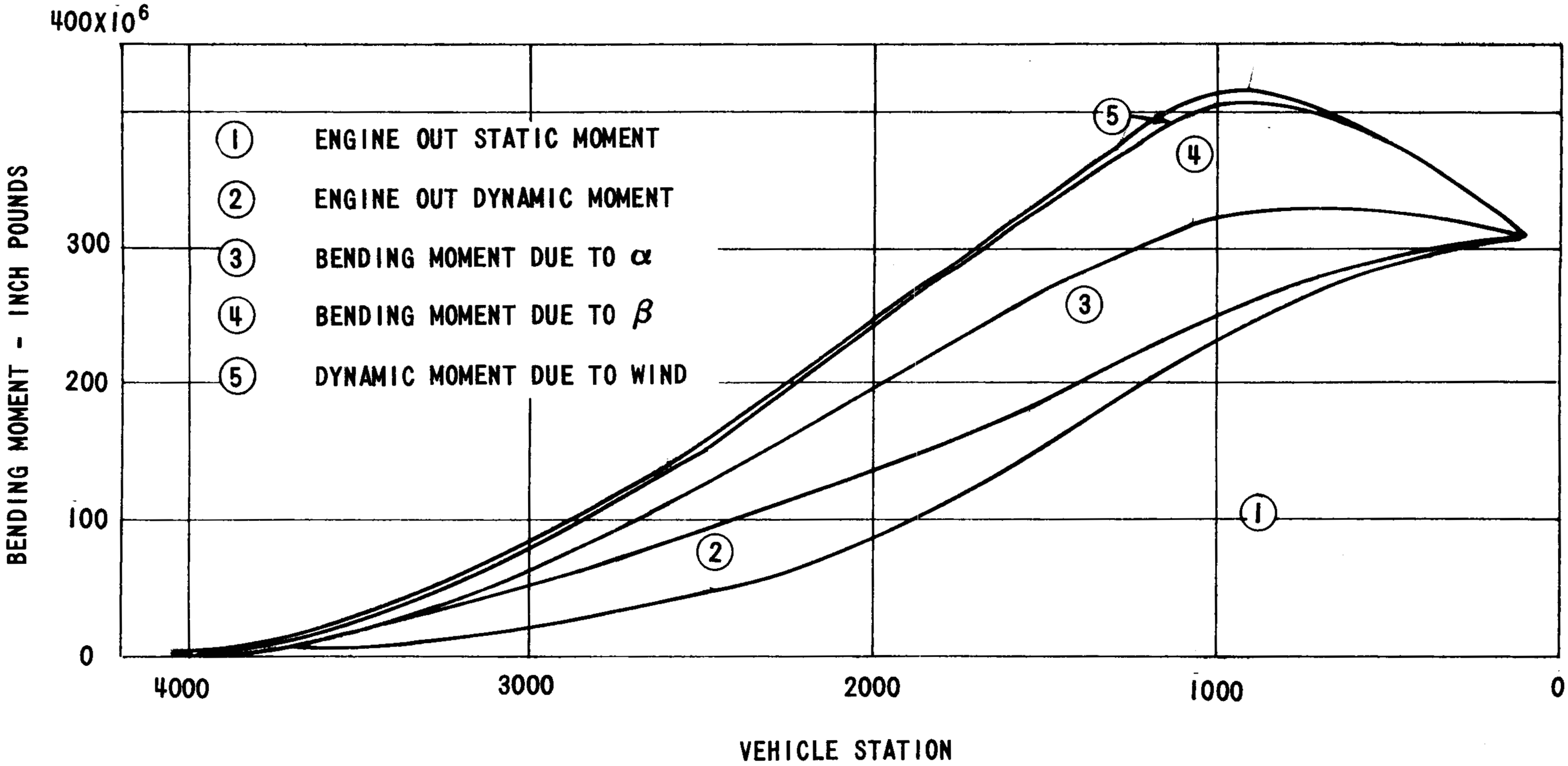


FIGURE 9 - SATURN V - BENDING MOMENT ONE ENGINE-OUT
t = 70 SEC., 45 M/SEC WIND (88 KNOTS)

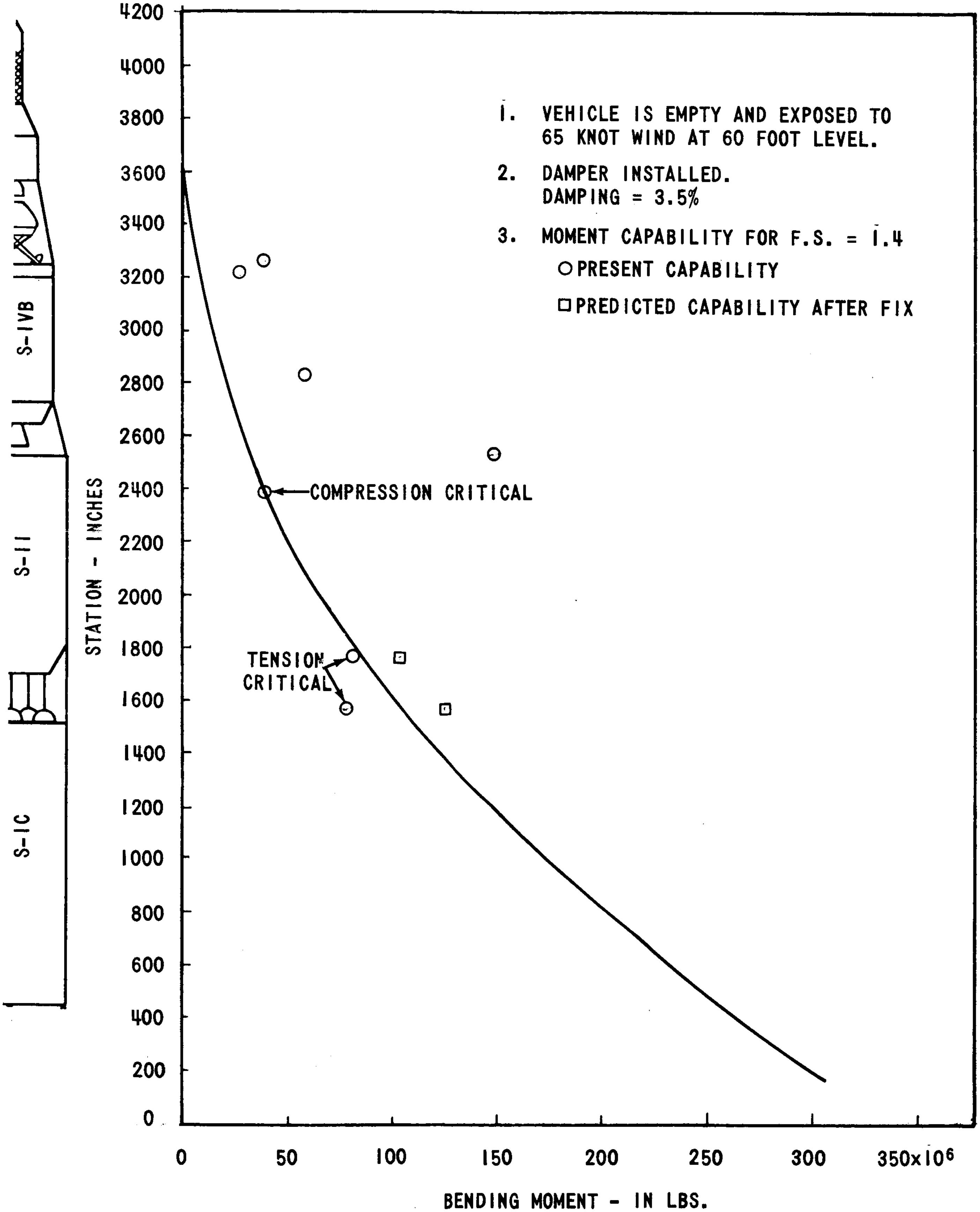


FIGURE 10 - SATURN V (AS-503, 504 & SUBS) GROUND WIND BENDING MOMENT VS. STATION

SA-501 COMPRESSION STRUCTURAL CAPABILITY (ULTIMATE)

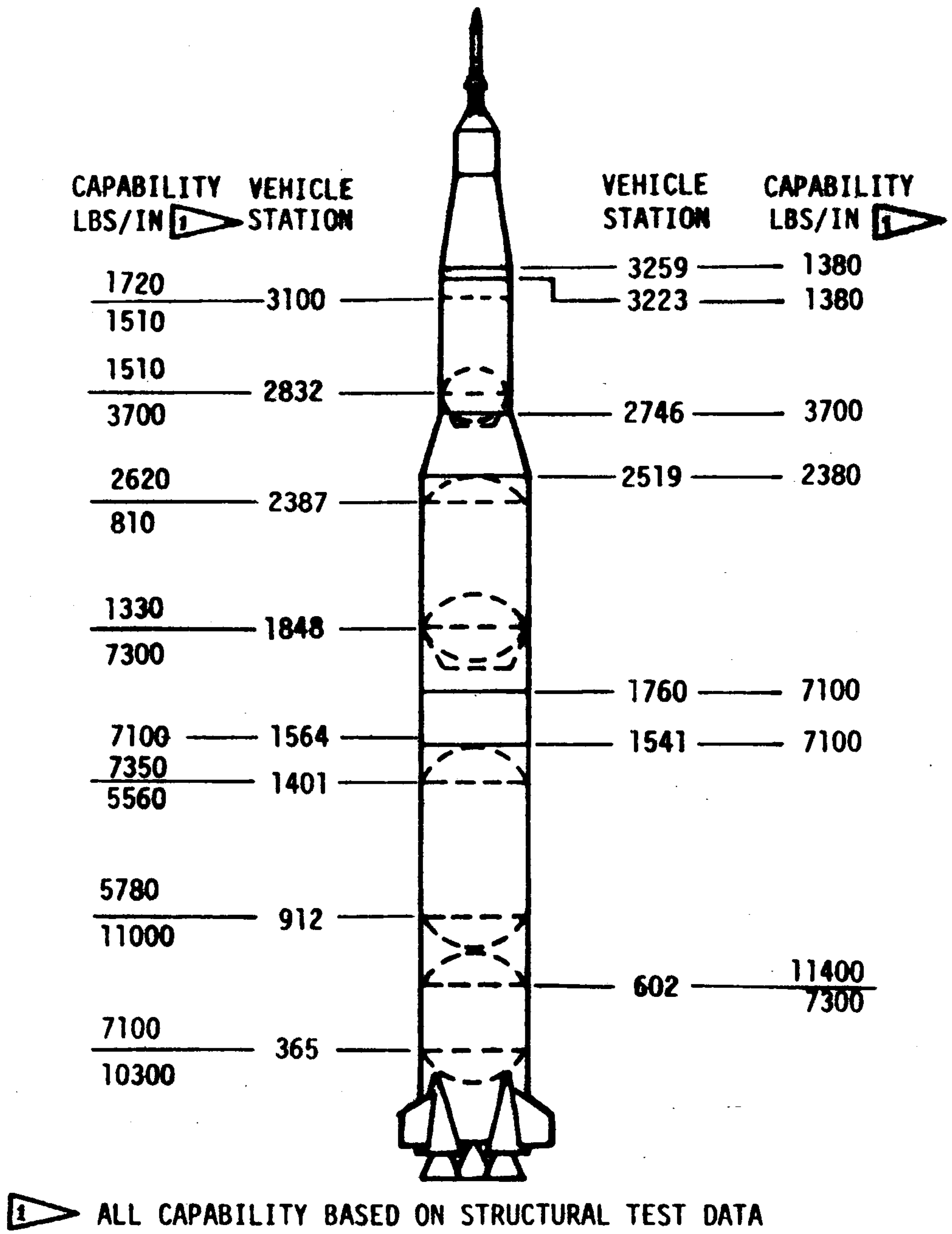
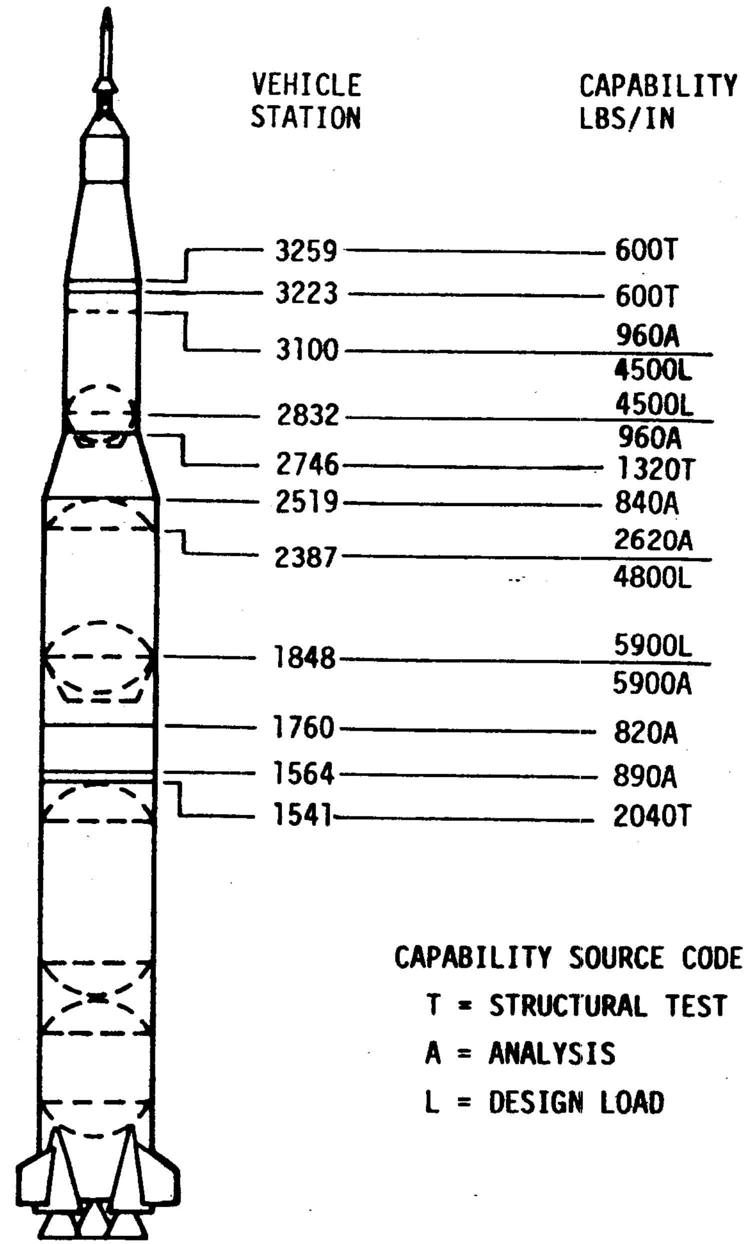


FIGURE 11

SA-501 TENSION STRUCTURAL CAPABILITY (ULTIMATE)



CAPABILITY SOURCE CODE

T = STRUCTURAL TEST

A = ANALYSIS

L = DESIGN LOAD

FIGURE 12